ESL-TR-08-06-01

THE APPLICATION AND VERIFICATION OF ASHRAE 152-2004 (Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems) TO DOE-2.1e SIMULATION PROGRAM

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June 2008

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EXECUTIVE SUMMARY

This report describes the application and verification of duct model on DOE 2.1e version 119 using ASHRAE 152-2004 (Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems). It begins with a concept of duct model which is developed by ASHRAE and shows the application and the verification of the duct model to DOE 2.1e version 119 simulation program.

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Introduction

This report is a detailed description of the duct model on DOE-2.1e version 119 using ASHRAE 152-2004 (Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems).

DOE-2.1e FUNCTION method is used to apply the duct model to DOE-2.1e simulation program and the measured data from the case study house (Habitat for Humanity) is used for the primary verification test of applied duct model.

The verification test includes the simulation results from EnergyGauge developed by the FSEC.

Case Study House Information

The case study house located at Bryan, Texas is a single story Habitat for Humanity house built in 1997. This house has one living room, a dining room, a kitchen, a utility area, 3 bedrooms, 1 ½ bathrooms, a front and a back porch. The total area is 1,170 ft^2. Table 1 shows the material specification of the case-study house.

Table 1. Material used in construction

	Material
Floor	- 4" concrete slab and 30" deep ground beams which are 12" wide - Linoleum tile
Exterior walls	- Vinyl siding and ½" plywood wrapped with "Tyvek" moisture barrier - ½" gypsum, R-13 insulation - Composite 2x4" stud wall
Interior walls	- 2x4" stud wall - ½ "gypsum - Blown-in treated cellulose insulation.
Ceiling	- 5/8" fire coded gypsum board - 12" of blown-in fiberglass insulation.
Roof	- Composite shingles - 5/8" plywood deck - 2x4" trusses set at 24" centers
Window	- Double pane clear with aluminum frame, without thermal break

The heating, ventilation and air-conditioning system consists of a 10.5 SEER (Seasonal Energy Efficiency Ratio) air-conditioning unit (2.5 tons), a furnace with 80% AFUE (Annual Fuel Utilization Efficiency), and a 0.56 EF (Energy Factor) domestic hot water system with 40-gallon tank size.

Front side of case study house (facing northeast)

Back side of case study house (facing southwest)

Left side of case study house (facing southeast)

Right side of case study house (facing northwest)

Figure 1. Pictures from case study house.

Figures 2 to 4 describe how materials were used in construction and DOE-2.1e simulation model. Tables 2 to 4 specify thermal properties of the materials to develop DOE-2.1e simulation model. Figure 5 shows the 3-dimensional geometry of the building created by the DrawBDL program.

Since DOE-2 calculates the weight of building materials to find out custom-weighting factor, it was important to put the proper materials into the DOE-2 simulation model. To simplify the DOE-2 input model, the wall of the case-study house simulation input file was modeled with two different constructions, one presenting the framed area of 12.6% of the wall area, and another presenting the insulated area of 87.4% of the wall area. The roof of the case-study house input file was also modeled with two different constructions, one presenting the frame area of 18.9% of the roof area and another presenting non-frame area of 81.1% of the roof area.

The walls of the case-study house were constructed with 2x4 studs placed 24 inches on center. These walls had 3 ½ inches of cellular insulation blown into the cavity between the studs. The exterior of the house was vinyl sheathing over plywood with a TYVEK moisture barrier. The interior of the walls were ½ inch gypsum board. The windows were double-pane clear glazing with aluminum frame without thermal break. The ceilings were 5/8" gypsum board on 2 x 6" trusses with fiberglass insulation. The roof construction consisted of composite shingles on 5/8" plywood deck placed on 2x6" trusses set at 24" centers. Attic ventilation was provided by a continuous perforated vinyl soffit on all sides of the house.

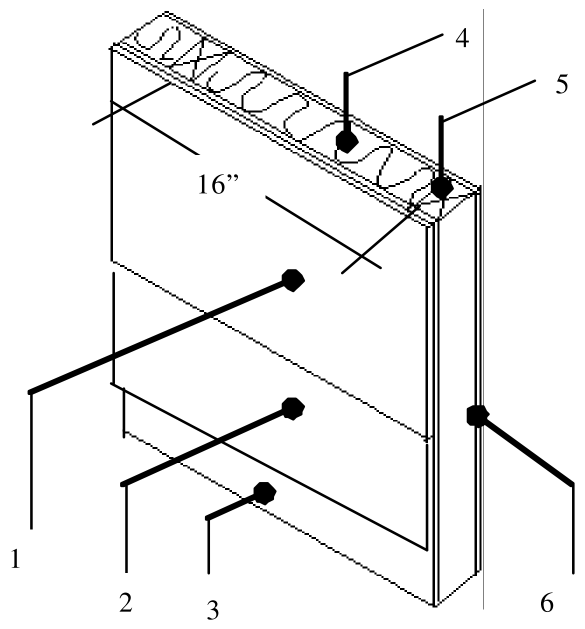

Figure 2. Details of wall construction.

Table 2. Details of wall thermal properties and DOE-2 code-word.

No.	Description	Thickness	Conductivity	Density	Specific heat	Resistance	DOE-2 code-word
		ft	Btu-ft/hr-ft^2-°F	lb/ft^3	Btu/lb-°F	hr-ft^2-°F/Btu	
1	VINYL-TILE				0.3	0.050	AV01
2	TYBEK MOISTURE PAPER					0.060	BP01
3	PLYWOOD-1/2IN	0.0417	0.0667	34	0.29	0.625	PW03
4	CELLULOSE-R13	0.2917	0.0225	3	0.33	12.964	IN13
5	STUD - 4INCH	0.3333	0.0667	32	0.33	4.997	WD05
6	GYPSUM-BOARD-1/2IN	0.0417	0.0926	50	0.2	0.450	GP01

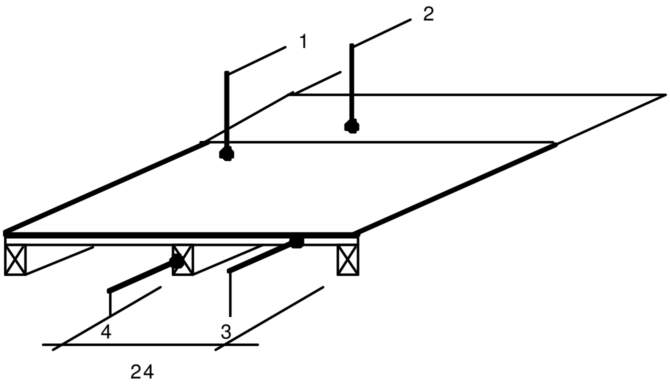

Figure 3. Details of roof construction.

Table 3. Details of roof thermal properties and DOE-2 code-word.

No.	Description	Thickness	Conductivity	Density	Specific heat	Resistance	DOE-2 code-word
		ft	Btu-ft/hr-ft^2-°F	lb/ft^3	Btu/lb-°F	hr-ft^2-°F/Btu	
1	SHINGLE-SIDING			70.00	0.35	0.44	AR02
2	PLASTIC-FILM-SEAL					0.01	BP03
3	PLYWOOD-3/8IN	0.05	0.07	34.00	0.29	0.71	PW04
4	STUD-6IN	0.50	0.07	32.00	0.33	7.14	

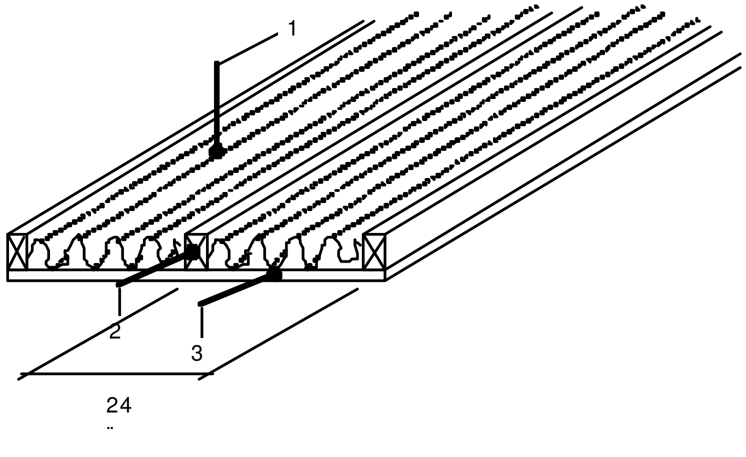

Figure 4. Details of ceiling construction.

Table 4. Details of ceiling thermal properties and DOE-2 code-word

No.	Description	Thickness	Conductivity	Density	Specific heat	Resistance	DOE-2 code-word
		ft	Btu-ft/hr-ft^2-°F	lb/ft^3	Btu/lb-°F	hr-ft^2-°F/Btu	
1	WOOL-FIBER-R19	0.45	0.03	0.63	0.20	16.81	IN12
2	STUD-6IN	0.50	0.07	32.00	0.33	7.50	
3	GYPSUM-BOARD-5/8IN	0.05	0.09	50.00	0.20	0.56	GP02

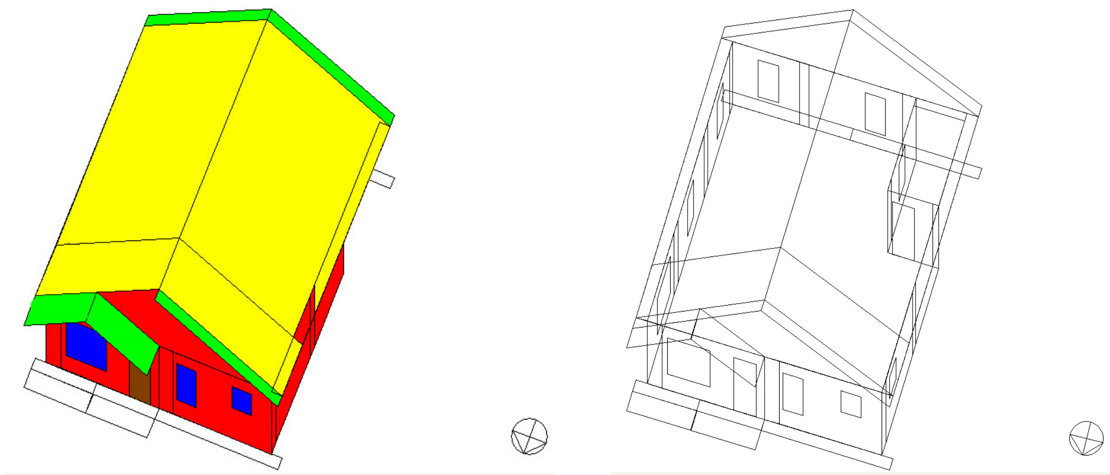

Figure 5. Image of the as-built case-study house simulation input using the DrawBDL program.

Diagram of Sensor Location

Several sensors were used to measure the indoor and outdoor environmental condition and energy consumption.

Figure 6 shows the location of each sensor. A gas meter was installed at the rear of the house and was connected with the house's gas system and the data logger. In order to collect data from the case-study house, a C180E Synergistics Data Logger was used and located in the backyard of the case-study house. This data logger has 16 power inputs, 16 digital inputs and 16 analog inputs, and can simultaneously monitored the analog, power and digital signals from the sensors located in the house. This Synergistics data logger can be remotely operated and data from logger can be downloaded using a computer program via modem using the Parset program that is supplied by the manufacturer. After recalibrating the sensors, they were connected to the data logger to measure indoor and outdoor environmental conditions, and the energy use of the house every 15 minutes. The temperature and humidity sensors were installed in the supply air duct, the end of the duct, attic space, and in the return grill. A flow meter was installed on the domestic hot water heater in the utility room and was connected to the Btu meter at the rear of the house. Three new portable sensors were also located in the attic to measure inside roof surface temperatures.

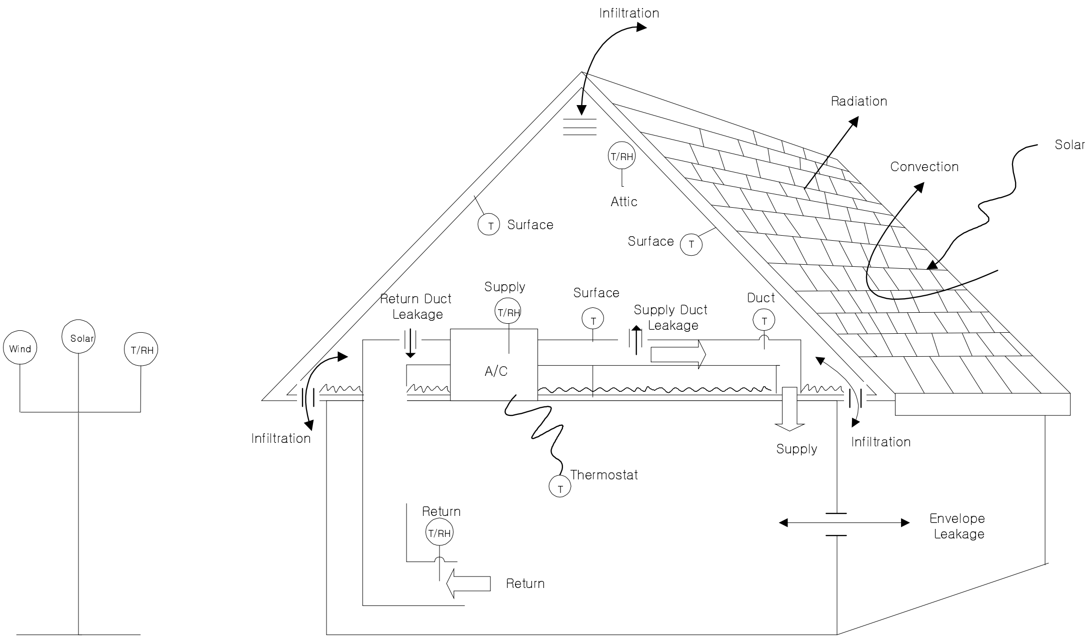

Figure 6. Diagram of sensor location.

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Measured Data for Whole Year

The case-study house consists of a conditioned space, an unconditioned space (attic), and a duct system located in the unconditioned space. Thus, measurements of thermal conditions and energy consumption of the case-study house were performed for the purpose of investigating the duct heat loss / gain to the unconditioned space and the pattern of energy use.

Figure 7 shows the measured attic, indoor and outdoor temperature as well as heating and cooling energy use for the period of January 1 to December 31, 2004. The attic temperature covers a wider range than that of the outdoor temperature, while the indoor temperature (conditioned space) is in a narrow range between 70 ºF and 80 ºF. It can be clearly seen that the cooling energy use increases during the summer period due to the air conditioner load. Also, the heating energy use increases during the winter period due to the use of the gas furnace. Summertime gas use is considerable due to domestic water heating, cooking and five pilot lights (furnace, DHW and stove-3).

Figure 8 shows the temperature characteristics of the attic, supply, duct (close to diffuser) temperature, and the temperature difference (diffuser temperature – supply temperature) to investigate the duct heat / gain in the attic space. In this plot, the negative value of the temperature difference between the duct (close to diffuser) and the supply temperature indicates that there is the heat loss to the attic space because the attic temperature is lower than the supply temperature. On the other hand, the positive value of temperature difference denotes that there is the heat gain from the attic space because the attic temperature is higher than the supply temperature.

Therefore, for the heating season (January, February, November and December), the negative values were used in the analysis. The positive values are used for the cooling season from May to October.

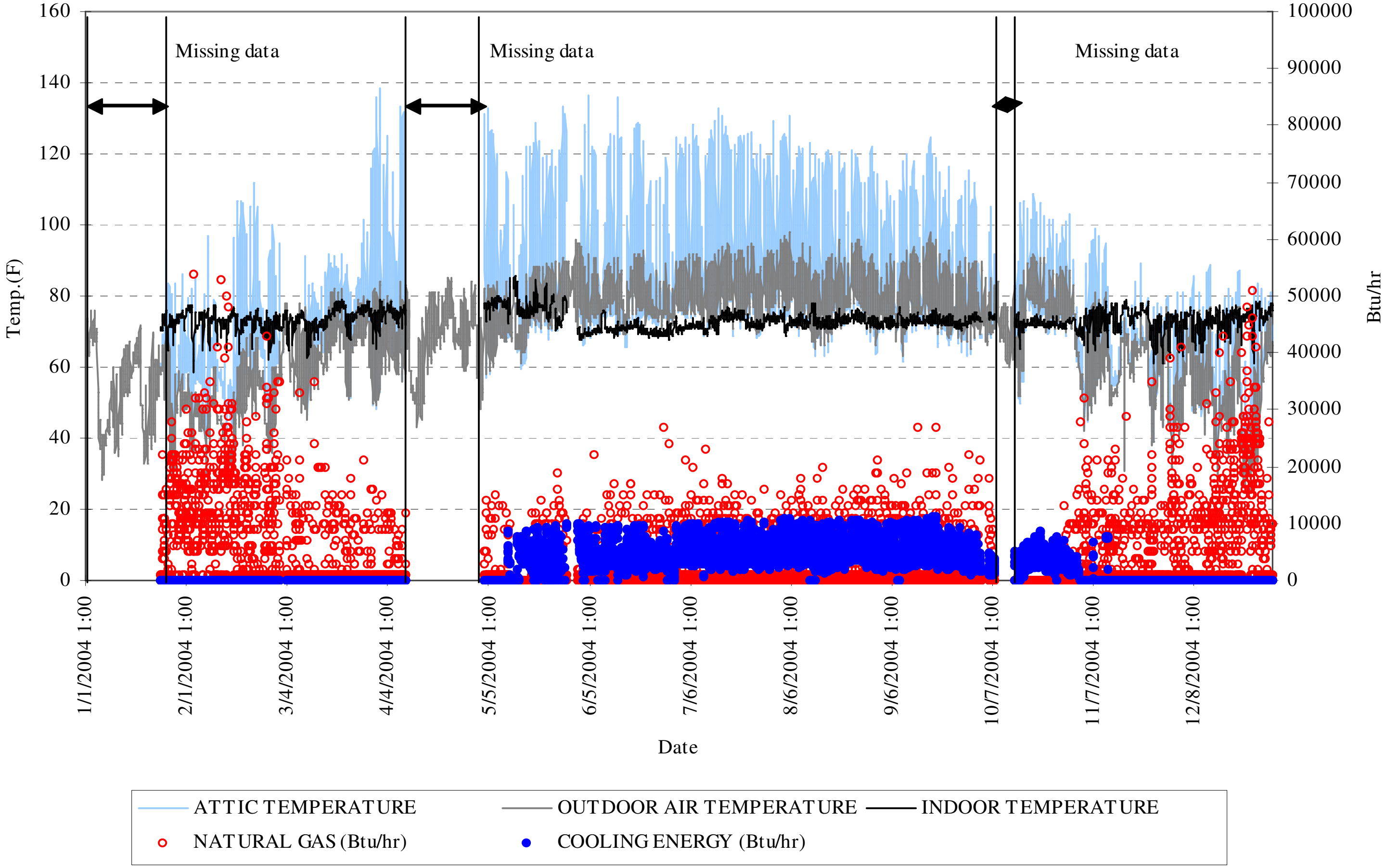

Figure 7. Measured attic, indoor, outdoor temperature, and heating and cooling energy.

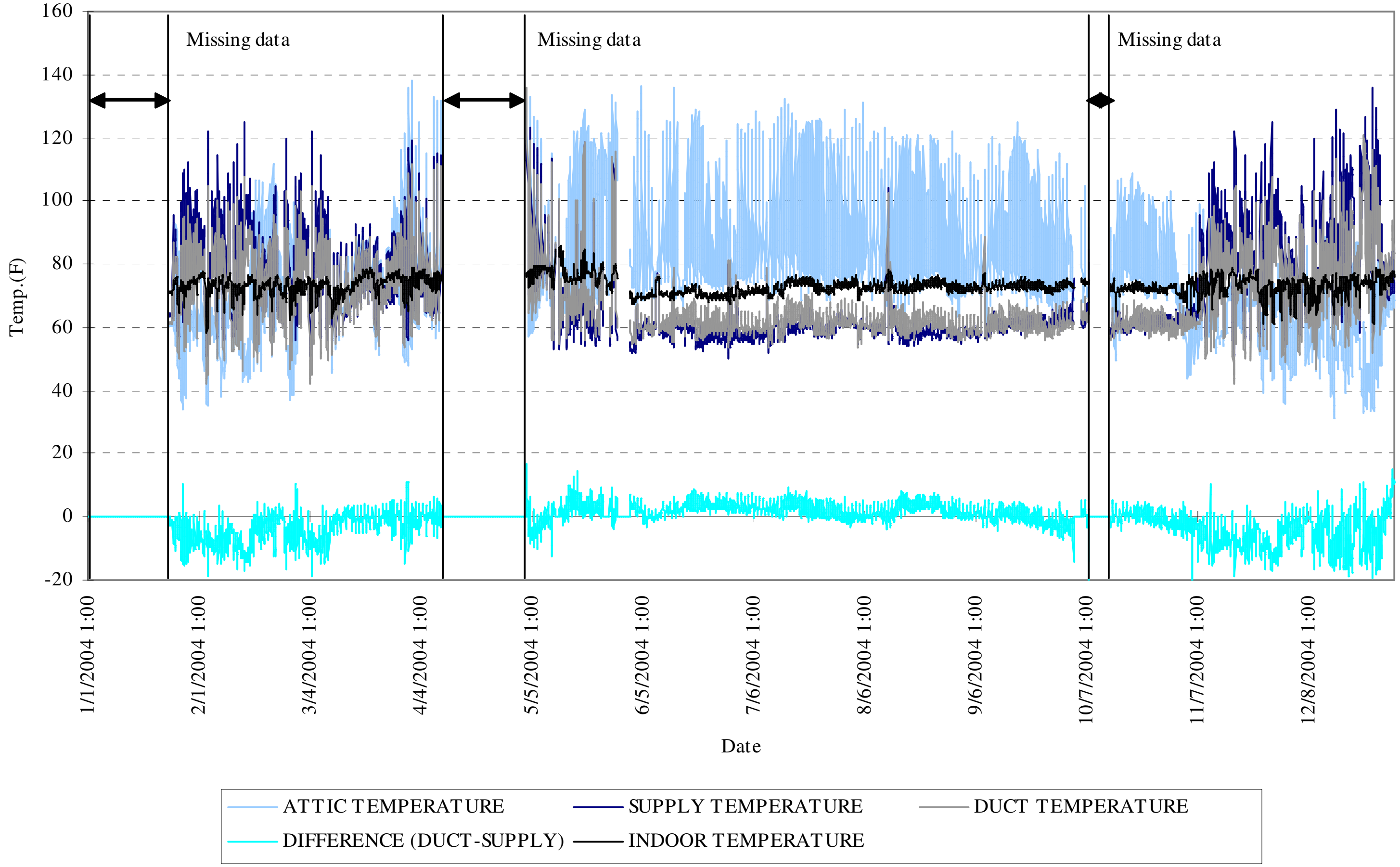

Figure 8. Measured attic, supply and duct temperature, and difference between duct and supply temperature.

Base-Case Model Calibration

In order to develop a calibrated DOE-2 simulation of the case-study house, a series of simulations were used to assess the improved accuracy. The calibration process included the calibration of the attic temperature, the zone temperature, the electricity use and the natural gas use. The calibration process for the attic and zone temperatures were performed using hourly measured and simulated data. In this simulation, the input model was divided into two adjacent zones, a living space and an attic space. In the base-case model calibration, an accurate attic temperature is critical since the attic space is the direct environmental condition for the duct system. Therefore, the hourly attic and indoor temperatures were calculated and reported by using the DOE-2 hourly report capability. Table 5 shows the attic temperature calibration process. Calibration process started from quick mode which used only U-value of building envelopes. Then layered materials were added to base-case model. Finally, several air change rates in the attic space were applied to achieve the accurate attic temperature.

Table 5. Attic temperature calibration process.

Run No.	Summer Period	Winter Period
1	Quick mode, Air-change = 0	Quick mode, Air-change = 0
2	Thermal mass mode, Air-change = 0, Infiltration Schedule = 1	Thermal mass mode, Air-change = 0, Infiltration Schedule = 1
3	Thermal mass mode, Air-change = 5, Infiltration Schedule = 1	Thermal mass mode, Air-change = 5, Infiltration Schedule = 1
4	Thermal mass mode, Air-change = 10, Infiltration Schedule = 1	Thermal mass mode, Air-change = 10, Infiltration Schedule = 1
5	Thermal mass mode, Air-change = 15, Infiltration Schedule = 1	Thermal mass mode, Air-change = 15, Infiltration Schedule = 1
6	Thermal mass mode, Air-change = 20, Infiltration Schedule = 1	Thermal mass mode, Air-change = 20, Infiltration Schedule = 1
7	Thermal mass mode, Air-change = 25, Infiltration Schedule = 1	Thermal mass mode, Air-change = 25, Infiltration Schedule = 1
8	Thermal mass mode, Air-change = 30, Infiltration Schedule = 1	Thermal mass mode, Air-change = 30, Infiltration Schedule = 1
9	Thermal mass mode, Air-change = 25, Infiltration Schedule = (1,7) (1) (8,20) (0.20) (21,24) (1)	Thermal mass mode, Air-change = 25, Infiltration Schedule = (1,7) (0.2) (8,17) (0.40) (18,24) (0.2)

Attic and Indoor Temperature Calibration

The calibrations for attic and indoor temperature were performed using the developed initial simulation input file of the case-study house. Attic temperature calibration was especially crucial because the well-calibrated attic temperature was the direct environmental conditions to the duct model in the attic space.

The hourly attic temperature comparisons shown in Figure 9 demonstrate that there were wide differences between the uncalibrated simulated and the measured attic temperatures. The uncalibrated, simulated attic temperatures from Figure 9, which used overall U-value of the attic space and pre-calculated ASHRAE weighting factors showed constant patterns compared to the measured attic temperatures.

Figure 10 shows the uncalibrated simulation (run #1) and measured results of the indoor temperature for the period August 1 to August 14, 2004

The calibration results of the attic temperature and indoor temperature for the period of August 1 to August 14, 2004 (summer season) are illustrated in the Figures 10 to 12. Figure 13 includes the Coefficient of Variation for the Root Mean Squared Error (CV(RMSE)) and the Mean Biased Error (MBE).

For the first simulation of the attic temperatures, the Coefficient of Variation for the Root Mean Squared Error (CV(RMSE)) was 14.5 %, and the Mean Biased Error (MBE) was 6.9 %. For the living space, CV(RMSE) was 2.5 %, and the MBE -1.3 %. In run #2, actual layered materials with DOE-2's custom weighting factors were added to the base-case model, called the "thermal mass mode", with the same infiltration rate as the quick mode model. This caused the CV(RMSE) and MBE for the attic temperature to be reduced from 14.5 % to 8.0 % and 6.9 % to 2.0 %.

These results showed that using layered materials with DOE-2's custom weighting factors predicted more accurately than using overall U-value and pre-calculated ASHRAE weighting factors.

For the conditioned space, in general, the model predicted the indoor temperatures fairly well since the indoor temperature were usually constant over the year. From run #3 and run #7, it was found that an infiltration schedule of 25 ACH for the nighttime (from 9:00 p.m. to 7:00 a.m.) and 5 ACH for the daytime (from 8:00 a.m. to 8:00 p.m.) yielded the best results. Therefore, a modified infiltration schedule was used on run #9, as shown in Figures 11 and 12 that the simulated temperatures were significantly closer to the actual data than the results of run #1 (Figure 9). In terms of statistical analysis, the CV(RMSE) has decreased from 14.5 % to 5.9 %, and MBE also has decreased from 6.9 % to 0.1 %.

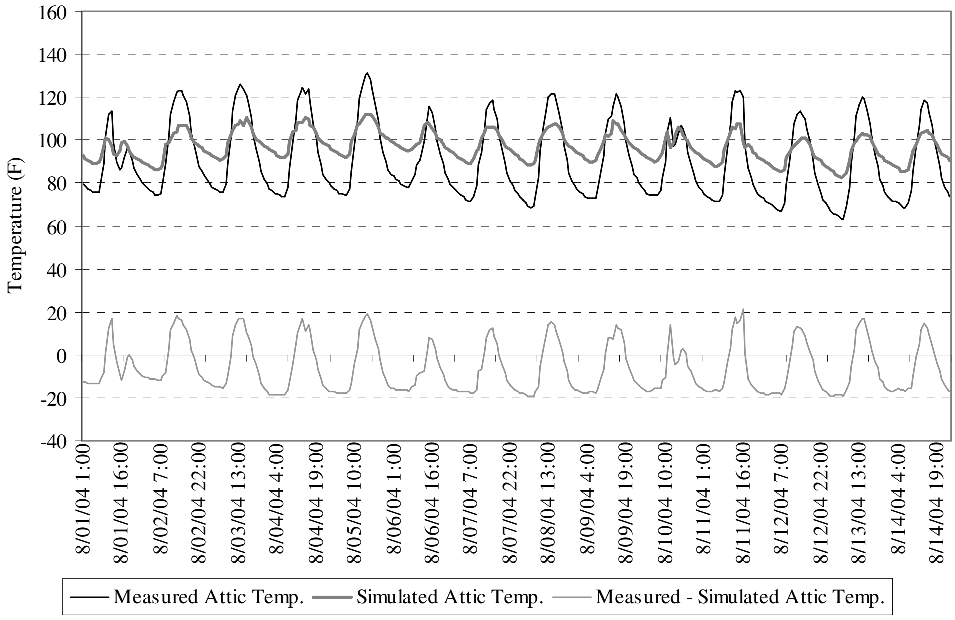

Figure 9. The uncalibrated simulation (run #1) and measured results of the attic temperature for the period August 1 to August 14, 2004.

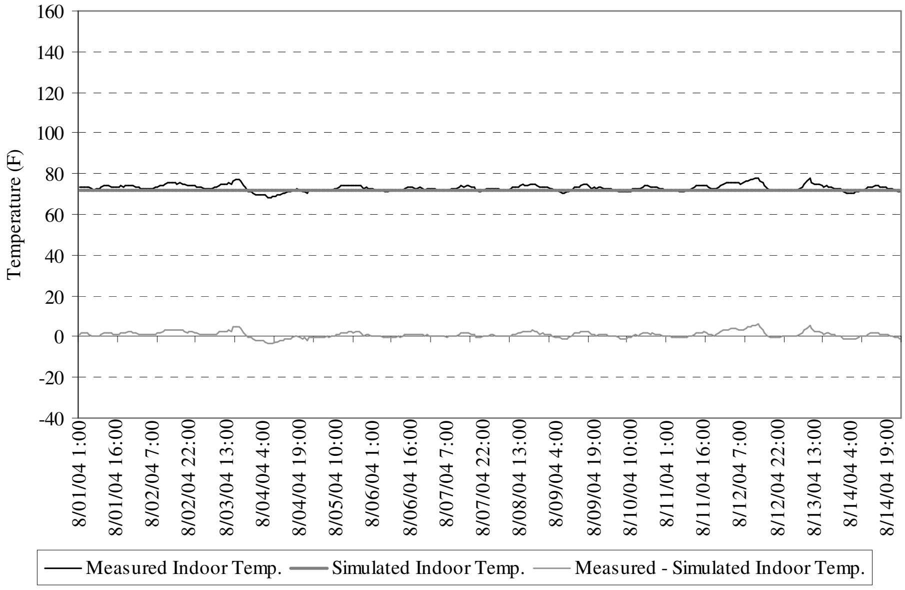

Figure 10. The uncalibrated simulation (run #1) and measured results of the indoor temperature for the period August 1 to August 14, 2004.

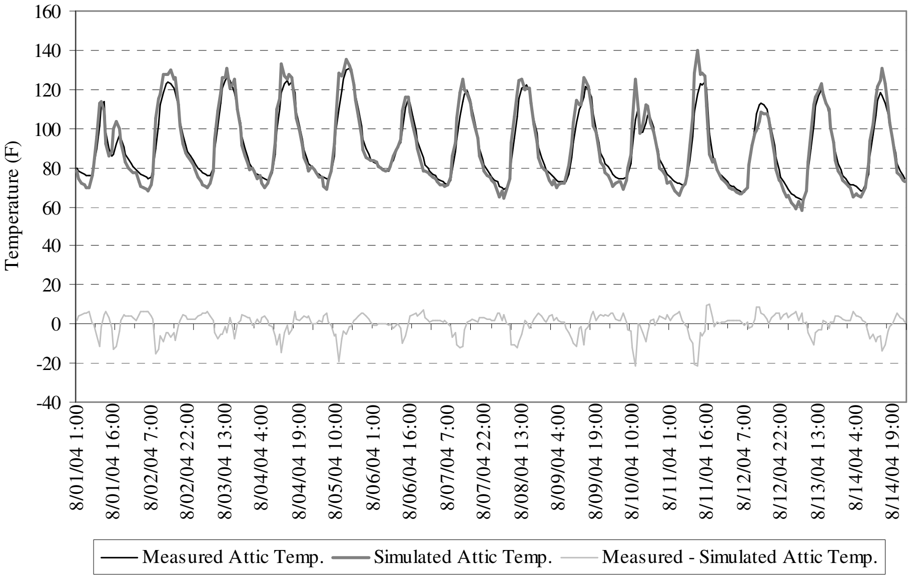

Figure 11. The calibrated simulation (run #9) and measured results of the attic temperature for the period August 1 to August 14, 2004.

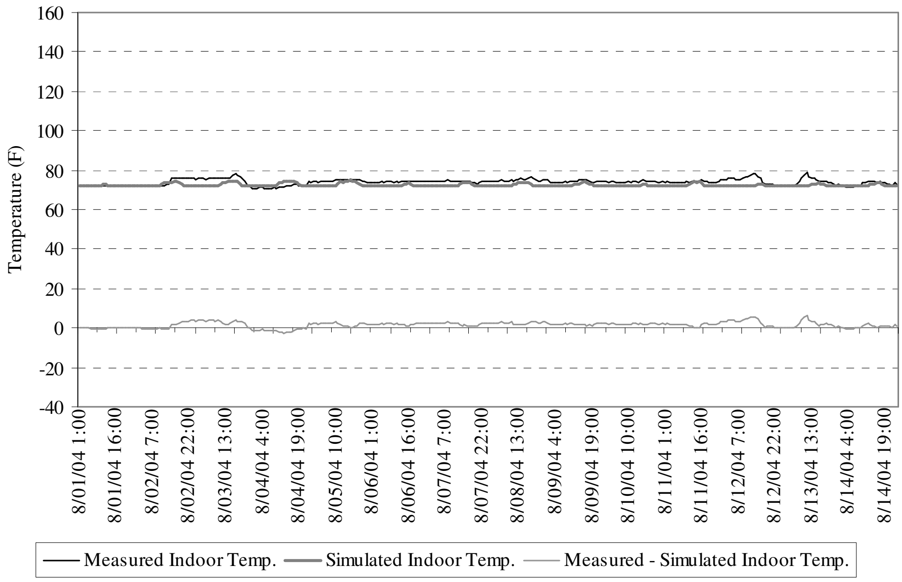

Figure 12. The calibrated simulation (run #9) and measured results of the indoor temperature for the period August 1 to August 14, 2004.

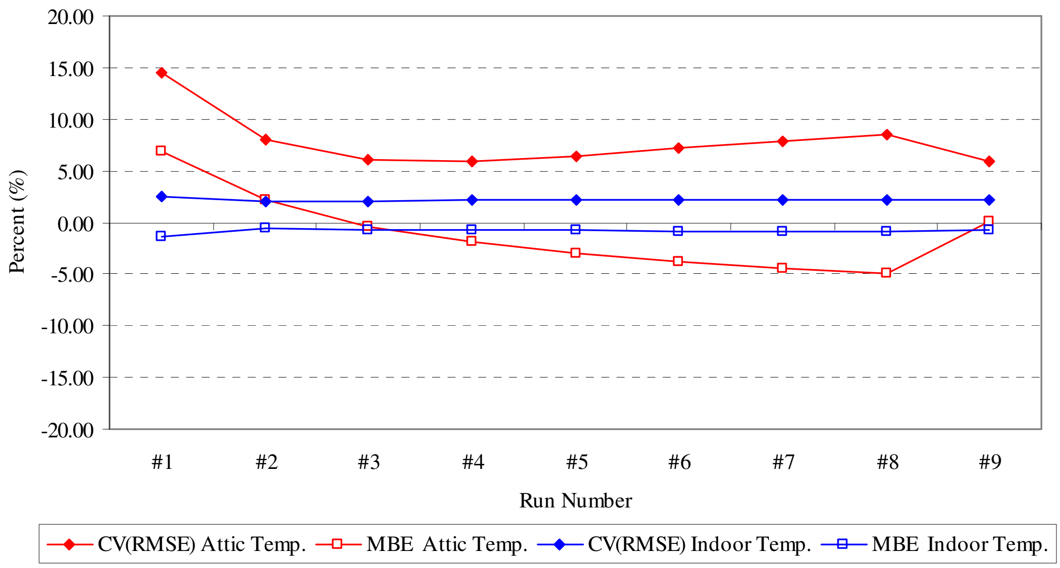

Figure 13. CV(RMSE) and MBE of attic and indoor temperature calibration.

The calibration results of the simulation of the attic temperature and indoor temperature for the period December 18 to December 31, 2004 (winter season) are also performed using the similar procedure in the calibration of the summer period.

From Figures 14 and 15, the uncalibrated attic and indoor temperatures which were performed using the quick mode, showed constant patterns as the summer period simulation. For the first simulation of the attic temperatures for the winter period, the Coefficient of Variation for the Root Mean Squared Error (CV(RMSE)) was 14.1 %, and the Mean Biased Error (MBE) was -1.7 %. For the living space, CV(RMSE) was 3.3 %, and the MBE was -0.4 %. In run #2, actual layered materials were modeled. The CV(RMSE) for attic temperature decreased to 13.71 % for CV(RMSE), but MBE increased to -4.7 %. Although the MBE of the attic temperatures of run #2 increased, the pattern of the attic temperatures was close to the measured attic temperatures. The reason for the MBE increase is that the measured attic temperature for winter period did not fluctuate as did for the summer period.

From run #3 and run #4, it was found that an ACH of 5 for the nighttime (from 6:00 p.m. to 7:00 a.m.) and ACH of 10 for the daytime (from 8:00 a.m. to 5:00 p.m.) yielded the best results. Therefore, the modified infiltration schedule was used on run #9. Figures 16 and 17 show that the simulated temperatures were closer to the actual data than the results of run #1 (Figures 14 and 15). In terms of statistical analysis, the CV(RMSE) has decreased from 14.1 % to 10.1 %, but MBE has increased from -1.7 % to 6.5 %, which were considered statistically acceptable (**Error! Reference source not found.**).

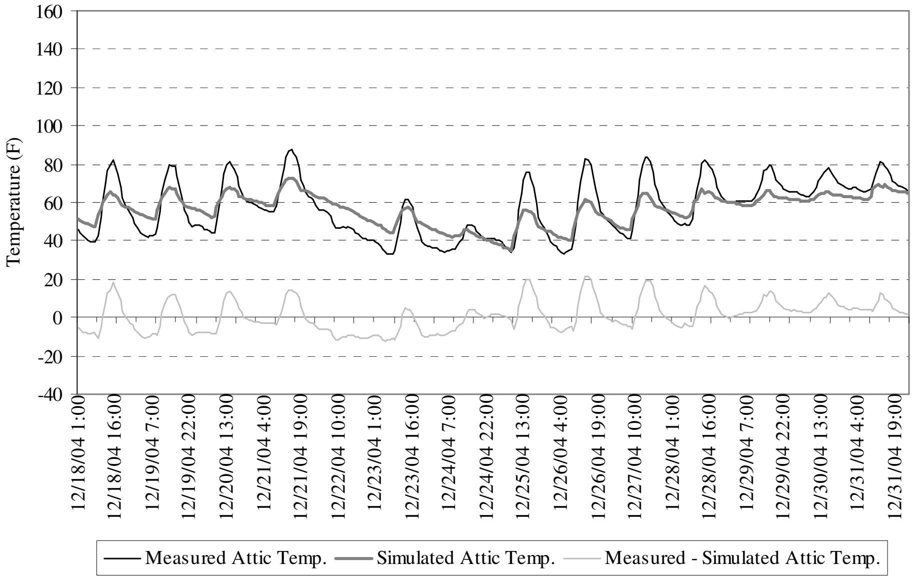

Figure 14. The uncalibrated simulation (run #1) and measured results of the attic temperature for the period December 18 to December 31, 2004.

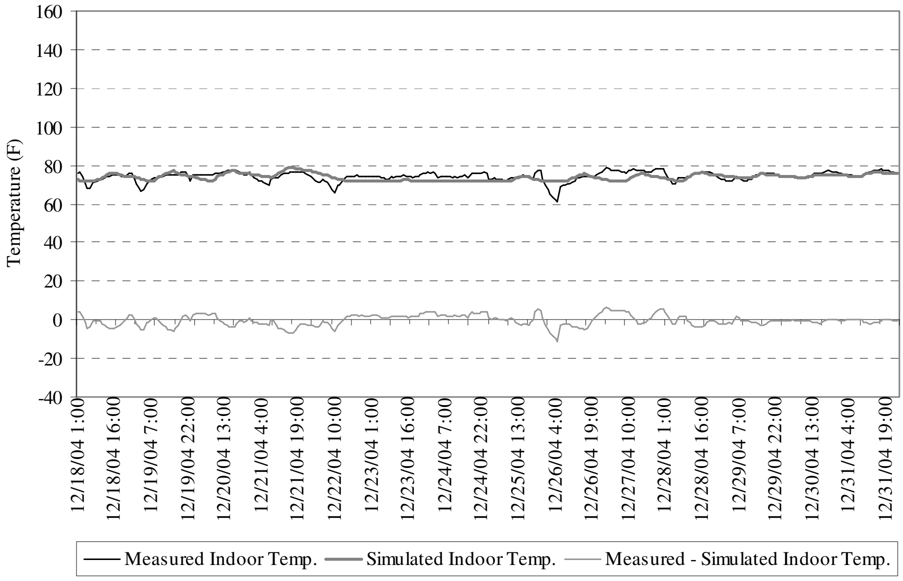

Figure 15. The uncalibrated simulation (run #1) and measured results of the indoor temperature for the period December 18 to December 31, 2004.

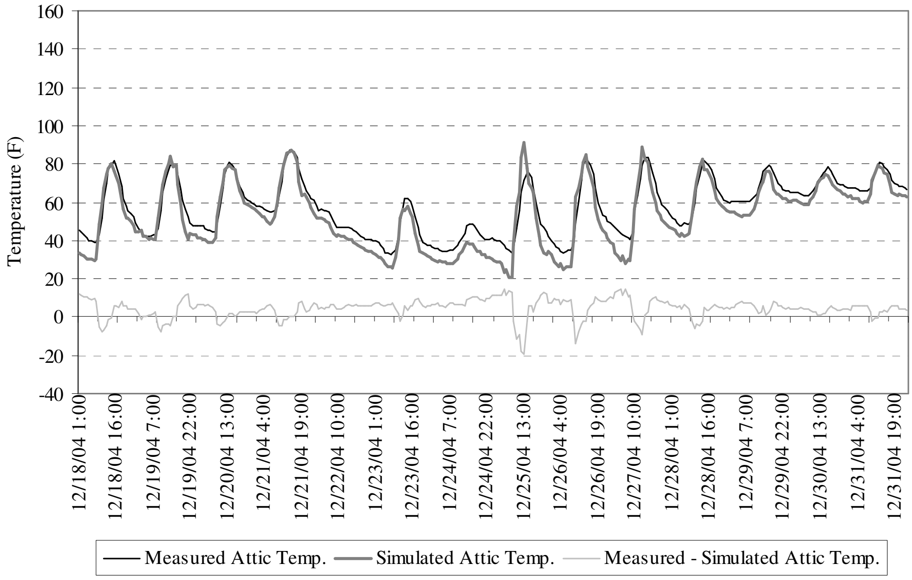

Figure 16. The calibrated simulation (run #9) and measured results of the attic temperature for the period December 18 to December 31, 2004.

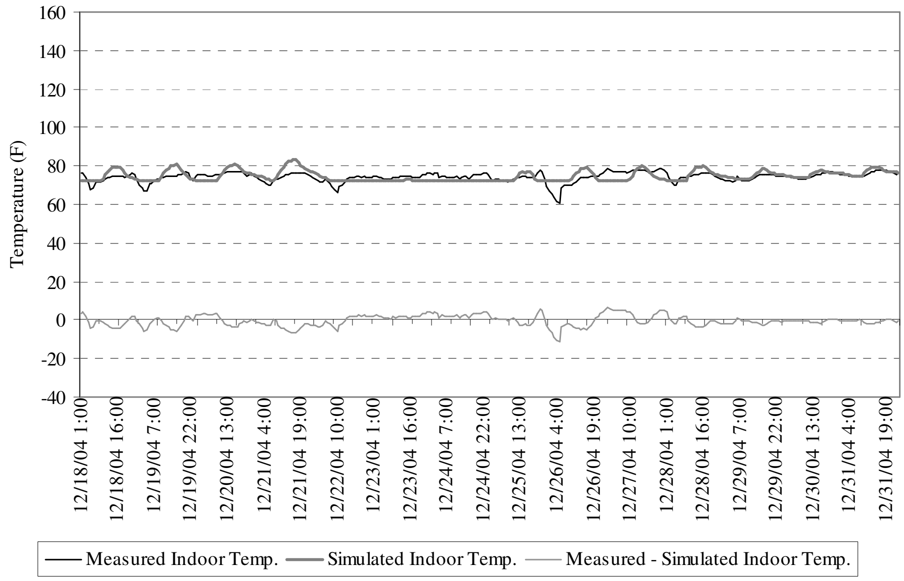

Figure 17. The calibrated simulation (run #9) and measured results of the indoor temperature for the period December 18 to December 31, 2004.

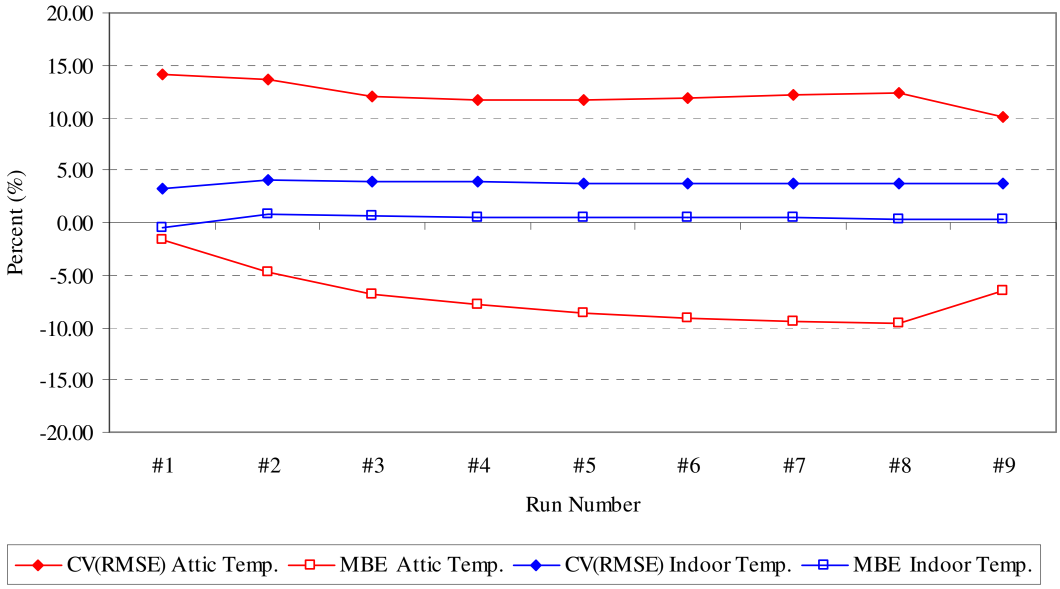

Figure 18. CV(RMSE) and MBE of attic and indoor temperature calibration.

Duct Model (ASHRAE 152-2004) on DOE-2.1e ver119

ASHRAE developed ASHRAE Standard 152-2004[1] - Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems to estimate design and seasonal efficiency for residential building systems. This calculation considers the impacts of duct leakage, location (i.e., attic space, crawl space, etc.), insulation level, climate, etc.

Figure 19 shows the concept of duct works which are located in two buffer zones, one for return side and one for the supply side (Palmiter and Francisco 1996[2]) and this concept was applied to DOE-2.1e simulation program using DOE-2 FUNCTION commands.

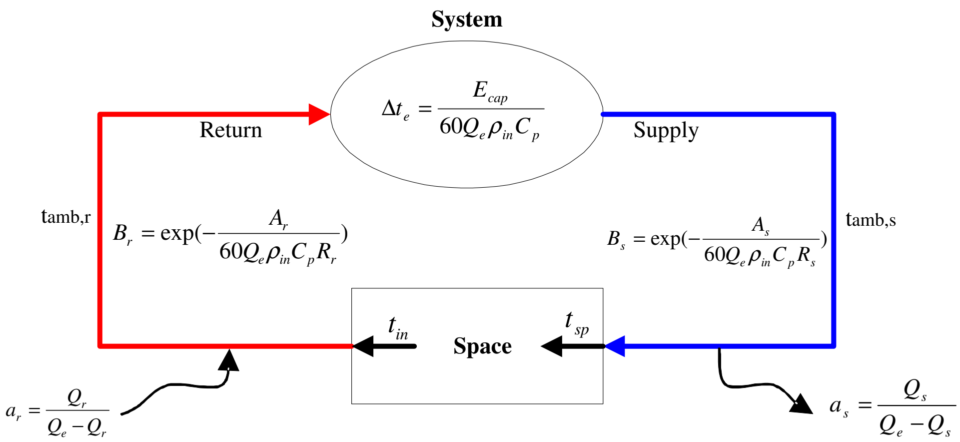

Figure 19. Schematic diagram of duct model (ASHRAE 152-2004).

Duct leakage rates of supply and return side of the case-study house were assumed as 10% for supply and return sides based on the research by Cummings (1991)[3].

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[1] ASHRAE (American Society of Heating, Refrigerating, and Air-conditioning Engineers). 2004. *Method of test for determining the design and seasonal efficiencies of residential thermal distribution systems (ASHRAE Standard 152-2004)*. Atlanta, GA: American Society of Heating, Ventilation and Air-conditioning Engineer.

[2] Palmiter, L., and P.W. Francisco. 1996. A practical method for estimating the thermal efficiency of residential forced-air distribution systems. *Proceedings of the 1996 ACEEE Summer Study on Energy-Efficient Buildings*: 96-112.

[3] Cummings, J., 1991. Investigation of air distribution system leakage and its impact in central Florida homes (FSEC-CR-397-91). Cocoa, FL: Florida Solar Energy Center.

Supply air flow (cfm) was 992cfm obtained from the previous research by Kootin-Sanwoo (2004)[4]. For the supply cfm measurement, air-handler fan flow measurement using an Alnor air flow meter was performed.

Following equations show the procedure of calculation of the delivery efficiency of the heating and cooling systems considering conduction loss and air leakage of supply duct and return duct side.

$$DE_{heating} = a_s B_s - a_s B_s (1 - B_r a_r) \frac{\Delta t_r}{\Delta t_e} - a_s (1 - B_s) \frac{\Delta t_s}{\Delta t_e}$$

$$DE_{cooling} = \frac{a_s Q_e \rho_{in}}{E_{cap}} \left(\frac{E_{cap}}{60 Q_e \rho_{in}} + (1 - a_r)(h_{amb,r} - h_{in}) + a_r C_p (B_r - 1) \Delta t_r + C_p (B_s - 1)(t_{sp} - t_{amb,s}) \right)$$

where,

B_s = conduction efficiency of supply duct = $\exp\left(\frac{-A_s}{60 Q_e \rho_{in} C_p R_s}\right)$,

B_r = conduction efficiency of return duct = $\exp\left(\frac{-A_r}{60 Q_e \rho_{in} C_p R_r}\right)$,

a_s = air leakage efficiency of the duct of supply duct = $\left(\frac{Q_e - Q_s}{Q_e}\right)$,

a_r = air leakage efficiency of the duct of return duct = $\left(\frac{Q_e - Q_r}{Q_e}\right)$,

E_{cap} = capacity of the equipment (Btu/hr),

Q_e = system air flow (CFM),

C_p = specific heat (Btu/(lb_m·ºF)),

Δt_e = temperature rise across the equipment (ºF) = $\frac{E_{cap}}{60 Q_e \rho_{in} C_p}$,

Δt_s = temperature difference between the building and the ambient temperature surrounding the supply (ºF) $= t_{in} - t_{amb,s}$,

Δt_r = temperature difference between the building and the ambient temperature surrounding the return (ºF) $= t_{in} - t_{amb,r}$,

t_{in} = temperature of indoor air (ºF),

t_{sp} = supply plenum air temperature (ºF),

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[4] Kootin-Sanwu, V. 2004. The development of low cost, energy efficient housing for low-income residents of hot and humid climates. Ph.D. Dissertation, Texas A&M University, College Station.

$t_{amb,s}$ = ambient temperature for supply ducts (ºF),

$t_{amb,r}$ = ambient temperature for return ducts (ºF),

$h_{amb,r}$ = enthalpy of ambient air for return (Btu/hr),

h_{in} = enthalpy of air inside conditioned space (Btu/hr),

A_s = supply duct area (ft^2),

A_r = return duct area (ft^2),

ρ_{in} = density of air (lb/ft^3),

R_s = thermal resistance of supply duct (hr-ft^2-ºF /Btu),

R_r = thermal resistance of return duct (hr-ft^2-ºF /Btu).

Figures 20 and 21 show the procedures of the function method developed for the DOE-2.1e to apply the duct model using concepts of ASHRAE 152-2004. Three function methods (SAVETEMP, DUCT, and DUCT 2) are used. 1) The SAVETEMP function saves the buffer zone temperature and conditioned space temperature to send these temperature data to the next function. 2) The DUCT function calculates the delivery efficiency using temperature. Data from the hourly report and user inputs and it modifies the Energy Input Ratio (EIR) every hour in proportion to the losses. The concept for this EIR modification came from Huang (personal communication, October 2001), 3) the DUCT2 function changes the modified EIR to the original value for the next calculation. The duct model on DOE-2.1e program was presented at Appendix.

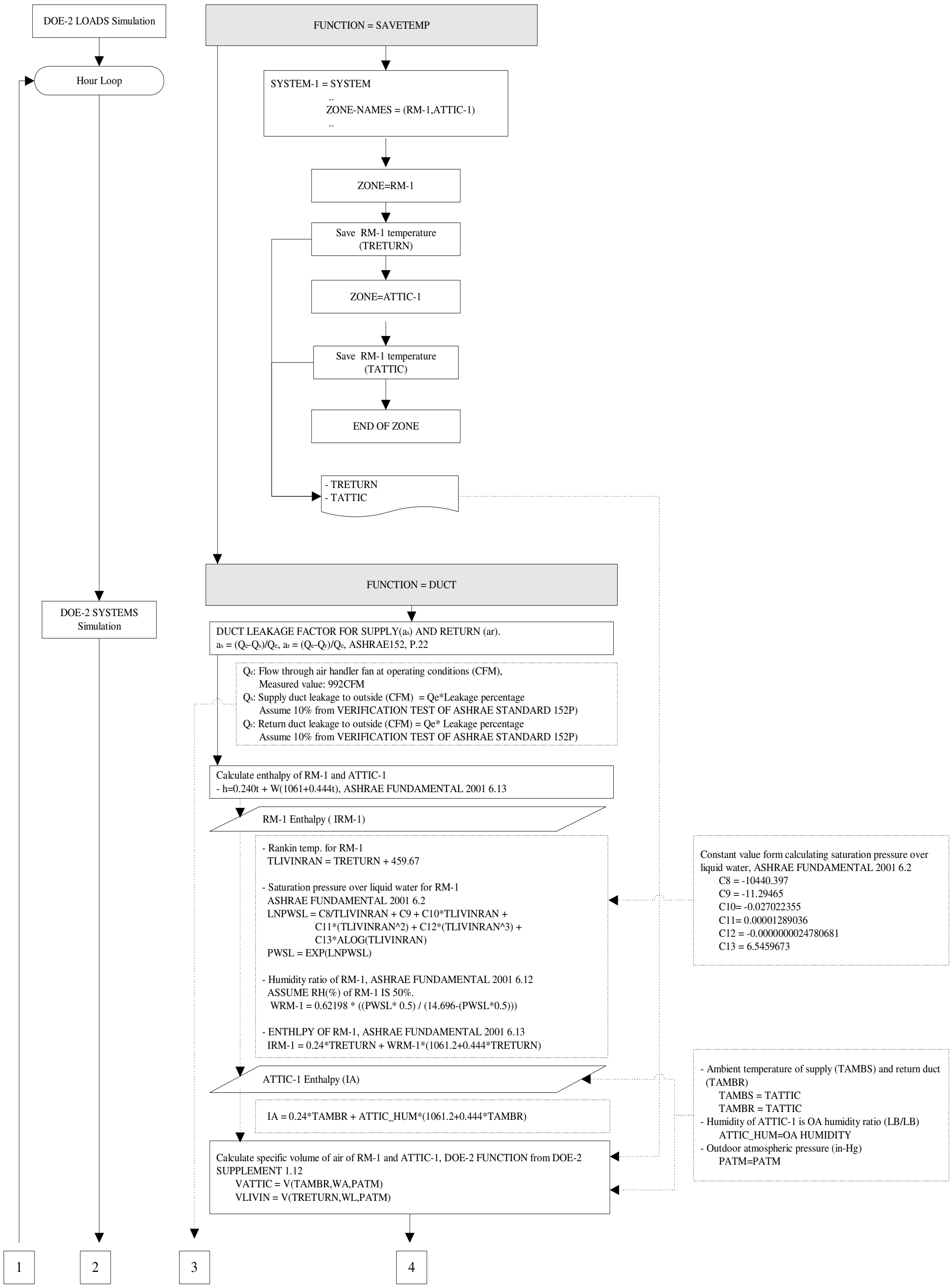


Figure 20. Diagram of DOE-2 FUNCTION command for ASHRAE 152-2004 duct loss model (a).

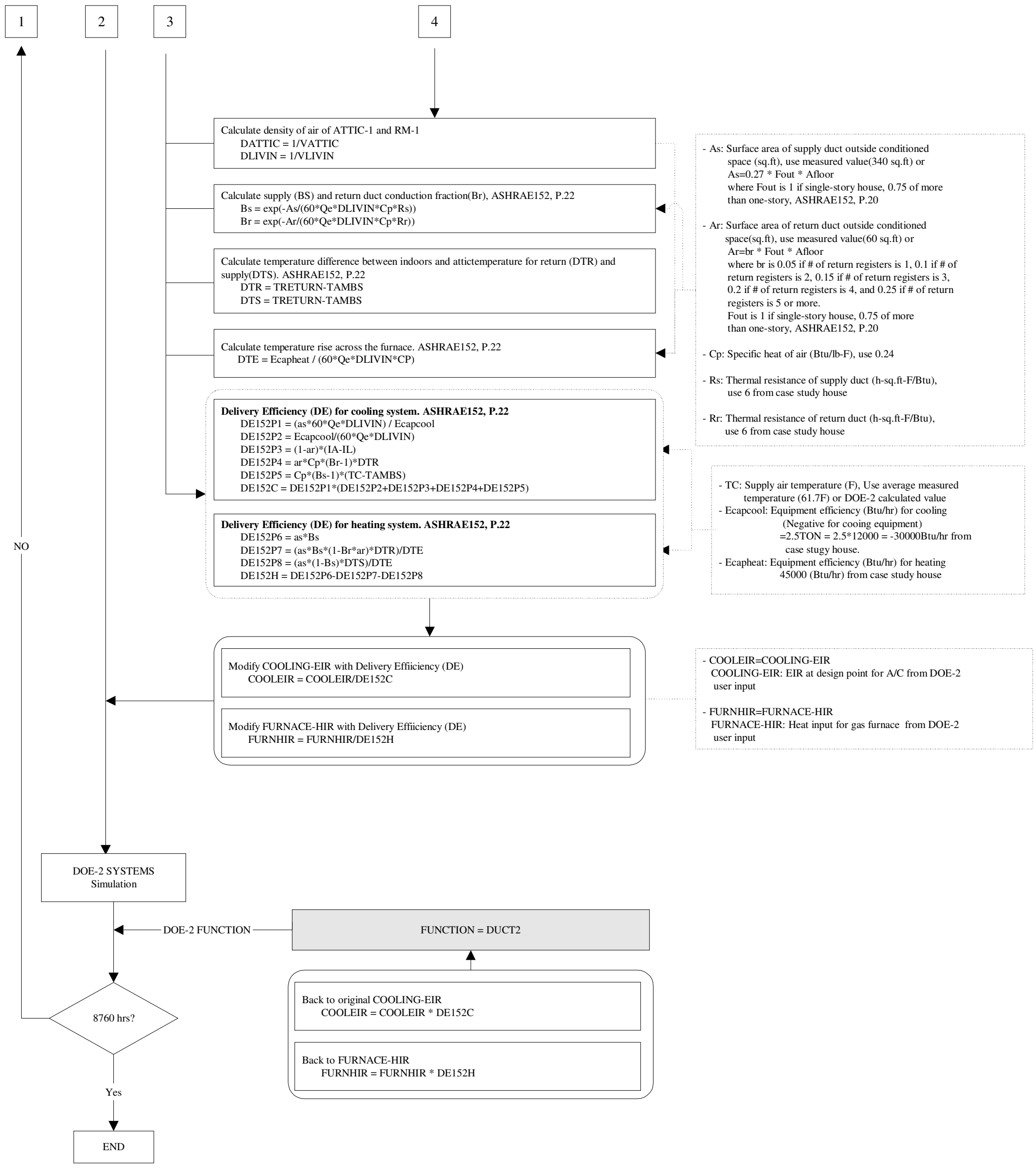


Figure 21. Diagram of DOE-2 FUNCTION command for ASHRAE 152-2004 duct loss model (b).

<u>Application of the Duct Model</u>

Once the calibration of the attic temperature and the indoor temperature were completed, duct model using the ASHRAE 152-2004 was incorporated into the calibrated DOE-2 model. As mentioned before, the exact simulation of the attic temperatures was critical, since attic temperature was the direct environmental condition of the duct systems.

Error! Reference source not found. illustrates temperatures, and cooling and heating energy over the entire year before duct model is incorporated into the temperature calibrated simulation models. The results show that the measured maximum cooling energy was 3.26 kW (11110.70 Btu/hr), but the simulated maximum cooling energy was 1.97 kW (6729.75 Btu/hr), since heat gains to duct system from attic space were not considered at this simulation. On average, the measured cooling energy use was 0.72 kW for one-year, but the simulated cooling energy use was 0.46 kW, which was lower than the measured cooling energy use. From two-week data from August 1 to August 14, 2004 (Figure 23), the results show the range of 0.44 kW to 3.20 kW for the measured results and 0.33 kW to 2.48 kW for the simulation results in the cooling energy use, which indicate that there is major difference between the measured and simulated cooling energy use (i.e., the simulated cooling energy had less energy consumption than the measured cooling energy.).

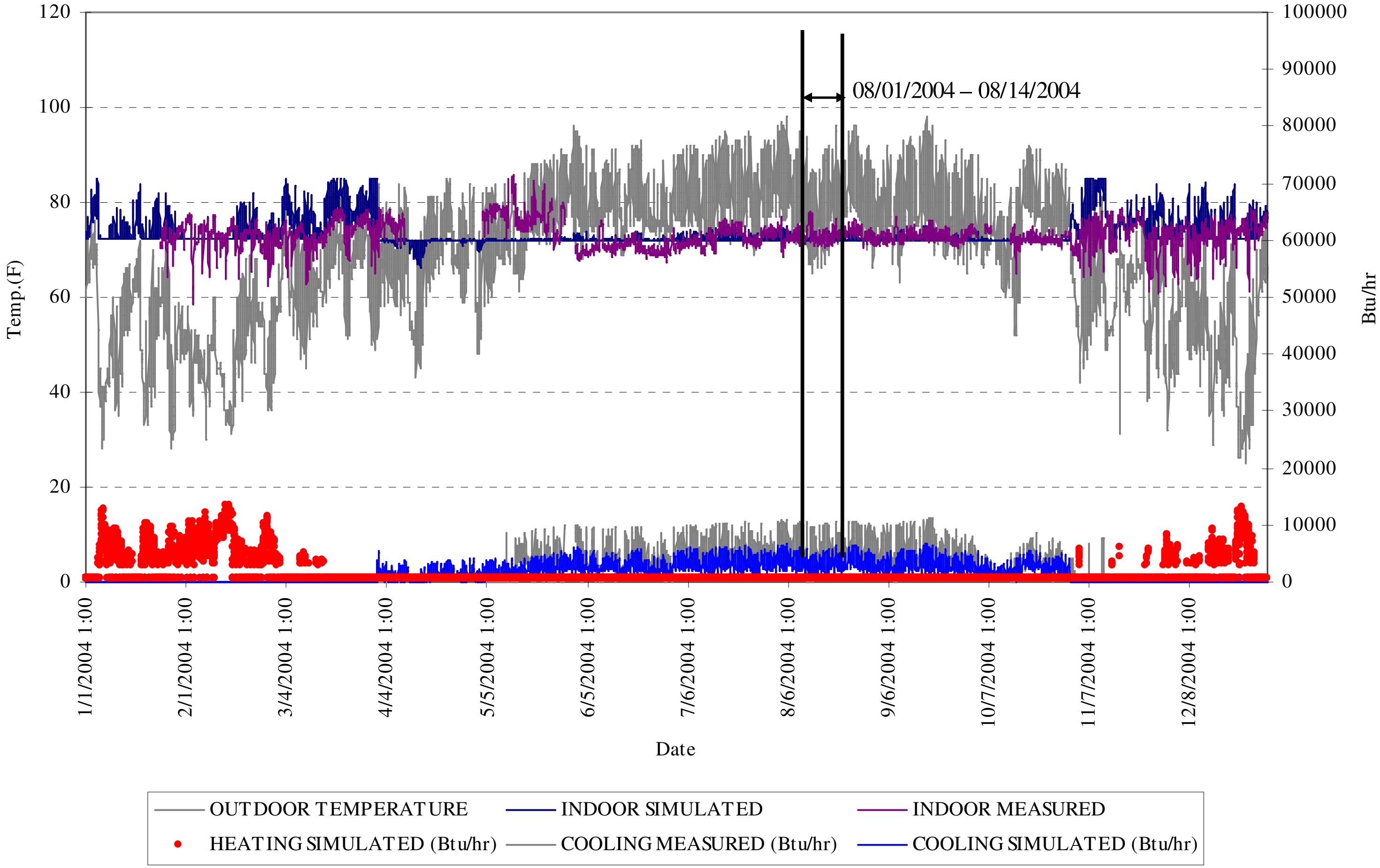
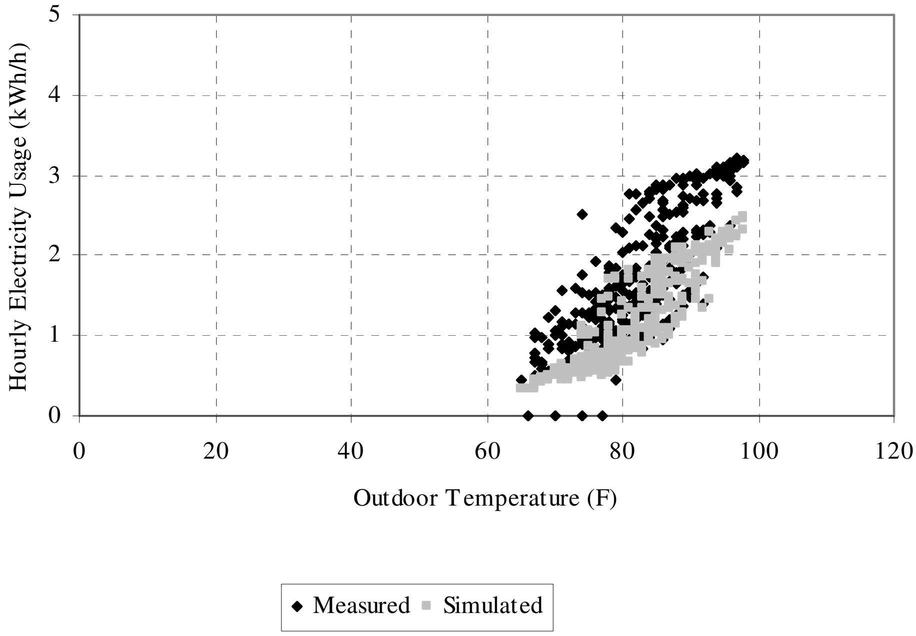


Figure 22. Temperature and cooling energy plots without duct model for the whole year.



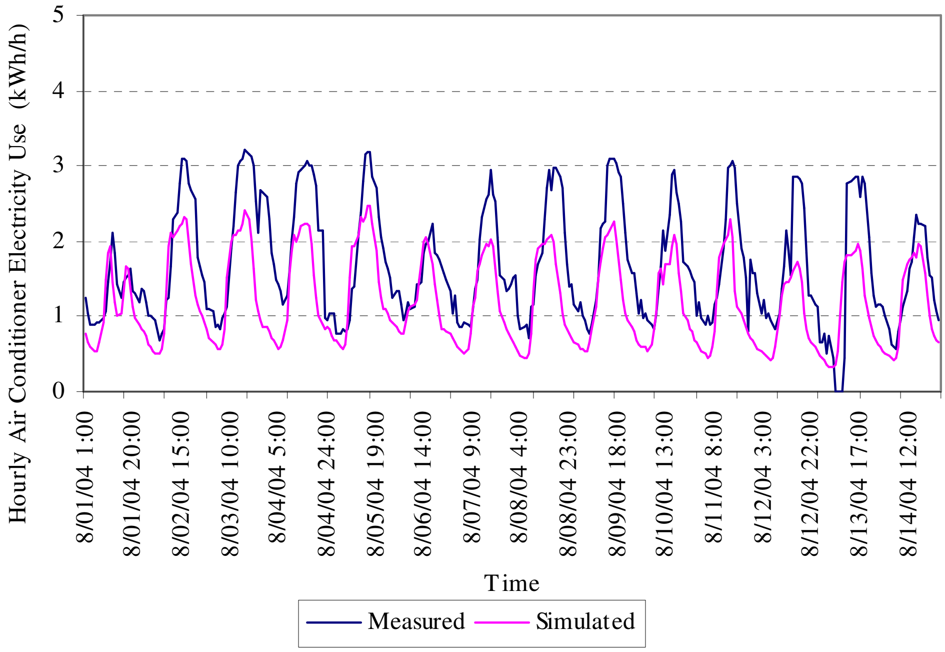


Figure 23. Cooling energy plots without duct model for two weeks (08/01/2004 – 08/14/2004).

In terms of statistic analyses, the Coefficient of Variation for the Root Mean Squared Error (CV (RMSE)) was 40.24 %, and the Normalized Mean Biased Error (MBE) was -29.10 % which were statistically inappropriate.

Figures 24 and 25 present results after duct model was incorporated to the DOE-2 simulation model. From a one-year plot (Figure 24), it was found that simulated cooling energy use increased compared to a one-year plot (**Error! Reference source not found.**) which the duct model was not applied to the DOE-2 simulation model.

On average, the simulated average cooling energy increased from 0.46 kW to 0.66 kW after the duct model was added to DOE-2 model. As shown in Figure 25, the range of simulated cooling energy was 0.38 kW to 3.44 kW after the duct model was incorporated into DOE-2 input, while the range of simulated cooling energy was 0.33 kW to 2.48 kW before incorporating the duct model into DOE-2 input.

From this plot, the amounts of cooling energy use were closer to the measured cooling energy use than the simulation results before duct model was applied to the DOE-2 simulation model. Furthermore, the Coefficient of Variation for the Root Mean Squared Error (CV (RMSE)) was reduced from 40.24% to 25.4 %, and the Normalized Mean Biased Error (MBE) was reduced from -29.10% to -8.25 %.

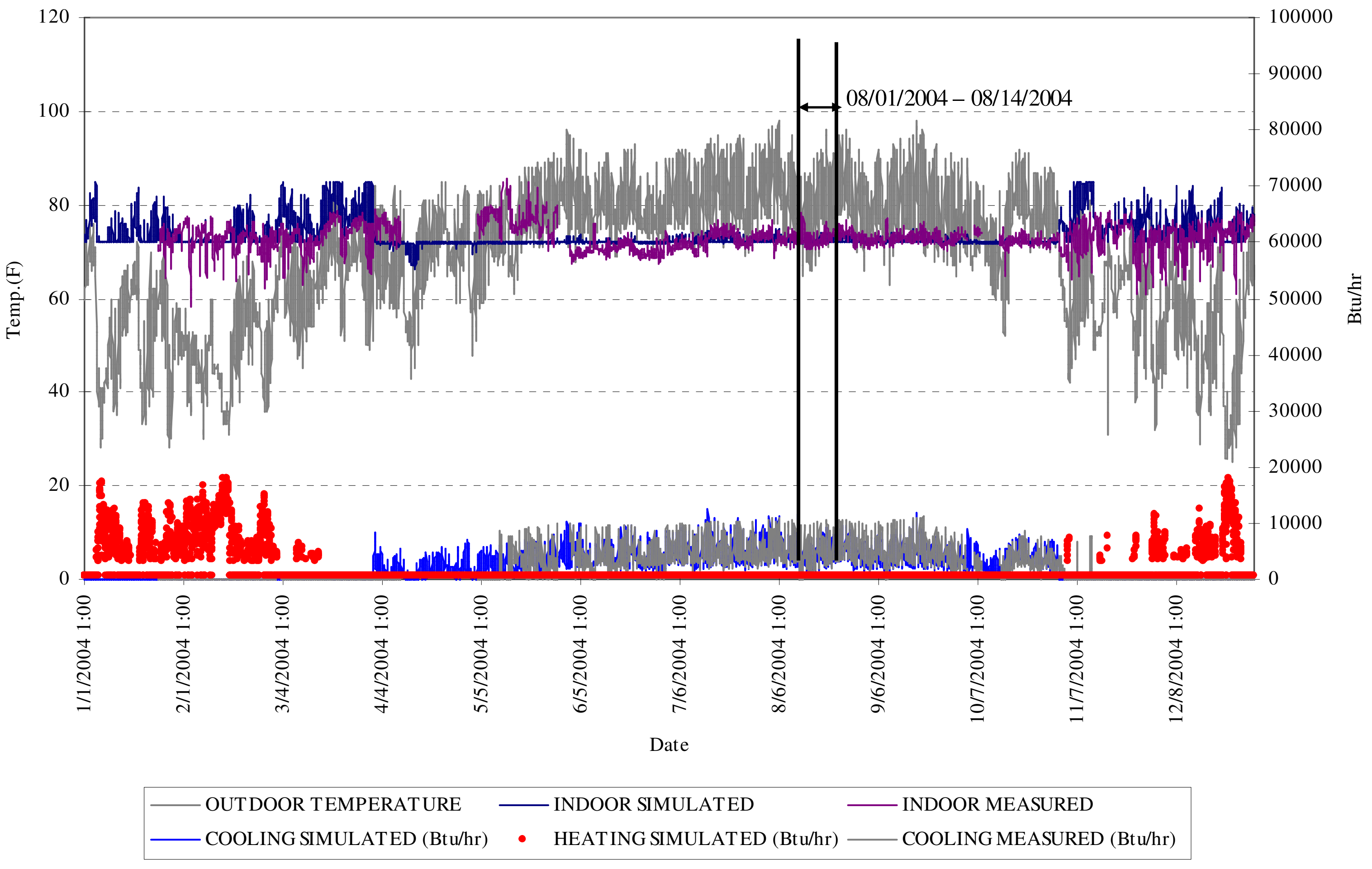


Figure 24. Temperature and cooling energy plots with duct model for whole year.

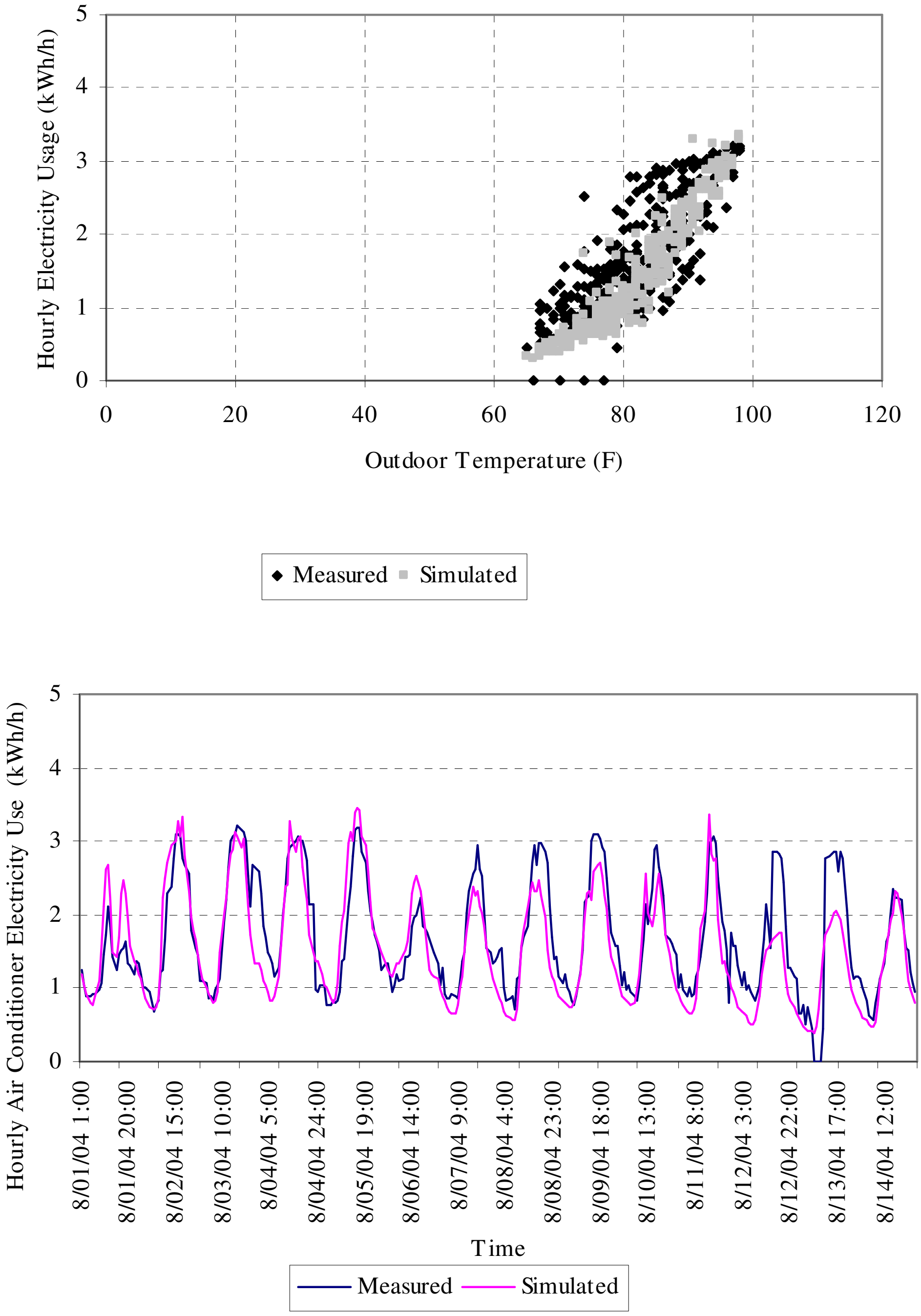


Figure 25. Cooling energy plots with duct model for two weeks (08/01/2004 – 08/14/2004) .

Verification of the Duct Model

Verification tests (Kim and Habler 2007)[5] were performed by varying duct insulation level, supply duct area, return duct area, supply duct leakage, return duct leakage, and ceiling insulation levels and compared with EnergyGauge program (version 2.42) by the Florida Solar Energy Center (FSEC). The results of tests show acceptable agreements for duct insulation level, supply duct area, return duct area, supply duct leakage, and ceiling insulation level. Agreement for return duct leakage test could not be obtained.

[5] Kim, S., and Haberl, J, 2007. Comparative Testing of the Combined Radiant Barrier Calculation and Duct Model in the ESL's DOE-2.1e NOx Emissions Calculator (ESL-TR-07-02-01). College Station, TX: Energy Systems Laboratory.

APPENDIX

Duct Model FUNCTION for DOE-2.1e

```
INPUT SYSTEMS  ..

SUBR-FUNCTIONS       RESYS-0=*DUCT*
                     RESYS-3Z=*SAVETEMP*
                     DAYCLS-4=*DUCT2*  ..


TITLE           LINE-1 *HABITAT FOR HUMANITY HOUSE, BRYAN,TEXAS*
                LINE-2 *1126 COMMERCE STREET, BRYAN TX 77803*
                LINE-3 *PH.D. DISSERTATION BY SEONGCHAN KIM*  ..


$***********************************************************************************************
$       PROGRAM:                        DOE-2 SIMULATION INPUT FILE
$
$       LANGUAGE:                       DOE-2.1E BDL VERSION 119
$
$       SPONSOR:                        TEXAS STATE LEGISLATURE
$
$       PURPOSE:                        This input file is a duct loss simulation using function
$                                       method of DOE-2.1e version 119 program.
$                                       The calculation methods follow ASHRAE 152-2004 (Method of Test
$                                       for Determining the Design and Seasonal Efficiencies of
$                                       Residential Thermal Distribution Systems).
$                                       To simulate duct loss on DOE-2 program, the following
$                                       parameter need to be specified;
$                                       1)SUPPLY AIR(CFM), 2)SUPPLY LEAKAGE, 3)RETURN LEAKAGE
$                                       4)SUPPLY AREA(SQ.FT), 5)RETURN AREA(SQ.FT),
$                                       6)R-VALUE FOR SUPPLY DUCT, 7)R-VALUE FOR RETURN DUCT
$                                       8)COOLING CAPACITY(BTU/HR), 9)HEATING CAPACITY(BTU/HR)
$
$       COPYRIGHT:                      TEES, 2006.
$                                       This program bears a copyright notice to prevent rights
$                                       from being claimed by any other party. This program
$                                       shall not be redistributed or sold without written
$                                       approval from the Texas Engineering Experiment Station
$                                       (TEES).
$
$                                       The program is distributed "as is". TEES DOES NOT
$                                       WARRANT THAT THE OPERATION OF THE PROGRAM WILL BE
$                                       UNINTERRUPTED OR ERROR-FREE, AND MAKES NO
$                                       REPRESENTATIONS OR OTHER WARRANTIES, EXPRESS OR IMPLIED,
$                                       INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES
$                                       OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.
$
$                                       No support service will be provided unless
$                                       written arrangements have been made to do so. Certain
$                                       manufacturers and trade names are mentioned in this code
$                                       for the purpose of describing  their product parameters
$                                       Such reference does not constitute an
$                                       endorsement or recommendation of such equipment, but is
$                                       provided for informational purposes only.
$
$       DEVELOPER:                      SEONGCHAN KIM
$                                       Graduate Assistant Research
$                                       Department of Architecture
$                                       Energy Systems Laboratory
$                                       Texas A&M University, College Station, TX 77843
$
$                                       JEFF HABERL  Ph.D, P.E
$                                       Professor
$                                       Department of Architecture
$                                       Energy Systems Laboratory
$                                       Texas A&M University, College Station, TX 77843
$                                       PHONE: (979)458-4315,   FAX: (979)862-2457
$                                       Email: jhaberl@esl.tamu.edu
$
$***********************************************************************************************


FUNCTION NAME = DUCT  ..
ASSIGN MON=IMO
       DAY=IDAY
       HR=IHR
       HUMRAT=HUMRAT
       PATM=PATM
       TRETURN = XXX24 $ RM-1 TEMP
       TATTIC = XXX25 $ ATTIC TEMP
       DE152C=XXX40
       DE152H=XXX41
       PDE152H=XXX42
       HPDE152H=XXX43
       DE152HHEATPUMP=XXX44
       FURNHIR=FURNACE-HIR
       COOLEIR=COOLING-EIR
       HEATEIR=HEATING-EIR
```

```
       NZ=NZ
       TC=TC       $SUPPLY TEMPERATURE
       CP=0.24     $SPECIFIC HEAT OF AIR, BTU/LB.F
       QSPL=P-SUPPLYAIR[]   $MEASURED, SUPPLY AIR(CFM),SY12
       SLF=P-SUPPLYLEAK[]     $SUPPLY LEAKAGE FRACTION(FROM "VERIFICATION TEST OF ASHRAE STANDARD 152P"),SY13
       RLF=P-RETURNLEAK[]     $RETURN LEAKAGE FRACTION(FROM "VERIFICATION TEST OF ASHRAE STANDARD 152P"),SY14
       AS=P-SUPPLYAREA[]      $MEASURED, SUPPLY DUCT AREA OF OUTSIDE CONDITIONED SPACE,SY15
       AR=P-RETURNAREA[]       $MEASURED, RETURN DUCT AREA OF OUTSIDE CONDITIONED SPACE,SY16
       RS=P-RSUPPLY[]        $THERMAL RESISTANCE OF SUPPLY DUCT (H-SQ.FT-F/BTU),SY17
       RR=P-RRETURN[]        $THERMAL RESISTANCE OF RETURN DUCT (H-SQ.FT-F/BTU),SY18
       ECAPCOOL=P-ECAPCOOL[] $2.5TON = 2.5*12000 = 30000BTU/HR, SY19
       ECAPHEAT=P-ECAPHEAT[] $SY20
       ..

 CALCULATE  ..

C DUCT LEAKAGE FACTOR FOR SUPPLY
       aas = (QSPL-(QSPL*SLF))/QSPL

C DUCT LEAKAGE FACTOR FOR RETURN
       aar = (QSPL-(QSPL*RLF))/QSPL

C CONSTANT VALUE FOR CALCULATING ENTHALPY, ASHRAE FUNDAMENTAL 2001 6.2
       C8 = -10440.397
       C9 = -11.29465
       C10= -0.027022355
       C11= 0.00001289036
       C12 = -0.0000000024780681
       C13 = 6.5459673

C AMBIENT TEMP. OF SUPPLY AND RETURN DUCT, ATTIC TEMP
       TAMBS = TATTIC
       TAMBR = TATTIC

C CALCULATION FOR ENTHALPY OF AMBIENT TEMP. FOR RETURN DUCT(ATTIC) FROM ASHRAE FUNDAMENTAL 2001 6.2

C      ENTHALPY OF ATTIC, ASHRAE FUNDAMENTAL 2001 6.13
       IA = 0.24*TAMBR + HUMRAT*(1061.2+0.444*TAMBR)

C      AMBIENT RANKIN TEMP. FOR LIVING SPACE
       TLIVINRAN = TRETURN + 459.67

C      SATURATION PRESSURE OVER LIQUID WATER FOR LIVING SPACE, ASHRAE FUNDAMENTAL 2001 6.2
       LNPWSL = C8/TLIVINRAN + C9 + C10*TLIVINRAN + C11*(TLIVINRAN**2) +
     + C12*(TLIVINRAN**3) + C13*ALOG(TLIVINRAN)
       PWSL = EXP(LNPWSL)

C      HUMIDITY RATIO OF LIVING SPACE, ASHRAE FUNDAMENTAL 2001 6.12
C      ASSUME RH(%) IS 50% ON LIVING SPACE
       WL = 0.62198 * ((PWSL* 0.5) / (14.696-(PWSL*0.5)))

C      ENTHLPY OF LIVING SPACE, ASHRAE FUNDAMENTAL 2001 6.13
       IL = 0.24*TRETURN + WL*(1061.2+0.444*TRETURN)


C      SPECIFIC VOLUME OF AIR FOR ATTIC AND LIVING SPACE, DOE-2 SUPPLEMENT 1.12
       VATTIC = V(TAMBR,WA,PATM)
       VLIVIN = V(TRETURN,WL,PATM)

C      DENSITY OF AIR FOR ATTIC AND LIVING SPACE
       DATTIC = 1/VATTIC
       DLIVIN = 1/VLIVIN

C      SUPPLY CONDUCTION FRACTION
       BS1 = -AS/(60*QSPL*DLIVIN*CP*RS)
       BS = EXP(BS1)

C      RETURN CONDUCTION FRACTION
       BR1 = -AR/(60*QSPL*DLIVIN*CP*RR)
       BR = EXP(BR1)

C      TEMPERATURE DIFFERENCE BETWEEN INDOORS AND AMBIENT FOR THE RETURN(F)
       DTR = TRETURN-TAMBS
       DTS = TRETURN-TAMBS

C      DTE, THE TEMPERATURE RISE ACROSS THE FURNACE
       DTE = ECAPHEAT / (60*QSPL*DLIVIN*CP)
C
       DE152P1 = (aas*60*QSPL*DLIVIN) / ECAPCOOL
       DE152P2 = ECAPCOOL/(60*QSPL*DLIVIN)
       DE152P3 = (1-aar)*(IA-IL)
       DE152P4 = aar*CP*(BR-1)*DTR
       DE152P5 = CP*(BS-1)*(TC-TAMBS)
       DE152C = DE152P1*(DE152P2+DE152P3+DE152P4+DE152P5)

       DE152P6 = aas*BS
       DE152P7 = (aas*BS*(1-BR*aar)*DTR)/DTE
       DE152P8 = (aas*(1-BS)*DTS)/DTE
       DE152H = DE152P6-DE152P7-DE152P8
       DE152HHEATPUMP = DE152P6-DE152P7-DE152P8
       PDE152H = FURNHIR/100
       HPDE152H = HEATEIR/2

98     IF (DE152C .GT. 1) DE152C = 1
       IF (DE152C .LT. COOLEIR) DE152C = COOLEIR
```

```
       COOLEIR = COOLEIR/DE152C

99     IF (DE152H .GT. 1) DE152H = 1
       IF (DE152H .LT. PDE152H) DE152H = PDE152H
       IF (DE152HHEATPUMP .LT. HPDE152H) DE152HHEATPUMP = HPDE152H
       FURNHIR = FURNHIR/DE152H
       HEATEIR = HEATEIR/DE152HHEATPUMP

C       PRINT 20,
C     + MON,DAY,HR,TATTIC,DE152C,DE152H,CFMINFATT
C20     FORMAT
C     + (3F3.0,' ',F5.1,' ',F5.3,' ',F5.3,' ',F6.0)

100    CONTINUE

       END

END-FUNCTION  ..
```

FUNCTION NAME = DUCT2 ..

```
ASSIGN MON=IMO
       DAY=IDAY
       HR=IHR
       TC=TC
       TH=TH
       FURNHIR=FURNACE-HIR
       COOLEIR=COOLING-EIR
       HEATEIR=HEATING-EIR
       TRETURN = XXX24 $ RM-1 TEMP
       TATTIC = XXX25 $ ATTIC TEMP
       DE152C=XXX40
       DE152H=XXX41
       ..

 CALCULATE  ..

       IF (DE152C .NE. 0 .AND. TC .GT. 0.1) GOTO 98
       IF (DE152C .EQ. 0) GOTO 100

98     COOLEIR = COOLEIR*DE152C

       IF (ABS(QH) .GT. 0.1) GOTO 99
       IF (DE152H .EQ. 0) GOTO 100

99     FURNHIR = FURNHIR*DE152H
       HEATEIR = HEATEIR*DE152H

100    CONTINUE
       END

END-FUNCTION  ..
```

```
FUNCTION NAME = SAVETEMP  ..
ASSIGN TRETURN = XXX24  $ RM-1 TEMP
       TATTIC = XXX25   $ ATTIC TEMP
       TNOW=TNOW
       NZ=NZ ..
 CALCULATE ..
       IF (NZ .EQ. 1) TRETURN=TNOW
       IF (NZ .EQ. 2) TATTIC=TNOW
      END

END-FUNCTION ..

FUNCTION NAME = SAVETEMP2 ..

ASSIGN TRETURN = XXX24  $ RM-1 TEMP
       TATTIC = XXX25   $ ATTIC TEMP
       TNOW=TNOW
       NZ=NZ ..
 CALCULATE ..
        IF (NZ .EQ. 1) TRETURN=TNOW
        IF (NZ .EQ. 2) TATTIC=TNOW
      END
END-FUNCTION  ..
```